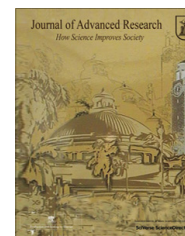




Cairo University
Journal of Advanced Research



ORIGINAL ARTICLE

The sunspot cycle no. 24 in relation to long term solar activity variation

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Received 1 January 2013; revised 20 February 2013; accepted 22 February 2013

Available online 30 March 2013

KEYWORDS

Solar cycle no. 24;
Hallstattzeit;
200-Year solar cycle

Abstract The solar minimum between solar cycles 23 and 24 during the period 2007–2009 has been the longest and deepest one at least since for the last 100 years. We suggest that the Sun is going to his next supercentennial minimum. The main aim of this paper is to tell about arguments concerning this statement. They are based on series of studies, which have been provided during the period since 1997 up to 2010. The progress of solar cycle 24 since its minimum at the end of 2008 up to the end of October 2011 in the light of long term solar activity dynamics is analyzed.

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Data, methods and analysis

At first, we studied in detail the solar activity behavior during the most continuous and full data set for the whole period of instrumental observations since 1610 up to 1995 – the so-called Group sunspot number series (GSN, the mean yearly number values) [1]. Three quasi-cyclic waves of increasing and decreasing the amplitude of 11 year sunspot Schwabe–Wolf’s cycles are clear visible with a mean duration of 80–100 years [2]. Their minima are well known by their labels “Maunder”

(1645–1715), “Dalton” (~1795–1830), and “Gleissberg (or) “Gleissberg–Gnevishev” (1898–1923). All these quasi-centennial waves are positioned over a general upward supercentennial trend, which starts since ~1700 AD. How regular are these minimums, is there some hierarchy between them, and what is the nature of the general trend are questions of high importance for certain long term solar activity forecasts. Obviously, the GSN series and even more the Zurich SSN series are too short for such tasks. That is why the studies of the so-called historical series, which give indirect information for solar activity during the preinstrumental era, are of very high importance.

There are two main types of “historical” data (see [3] and the reference therein): (a) based on ancient or medieval manuscripts and messages for naked eye visible sunspots, aurora, bright comets, extremal climatic events, earthquakes, or other phenomena which could be related directly or indirectly to low or high solar activity; (b) based on “cosmogenic” radioisotopes measurements (mainly ¹⁴C and ¹⁰Be). By using of different types of analysis, a main cyclic oscillation by duration of

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approximately 200 years in all series is detected. In context of radiocarbon data, it is popular as “de Vrie’s (or Swuess) oscillation.” Its minimums after 1000 AD are these of Oort, Wolf, Spoerer, Maunder, and Dalton in 11th, 13th, 15th, 17th, and 19th centuries, respectively. It is also clear established that Maunder minimum is the deepest from all ones, followed by Spoerer minimum. Obviously, the period of the both minimums, that is, 15th–17th centuries is the deepest phase of long term tendency, which is downward since ~ 1000 –1100 AD up to the Maunder minimum and upward after that. It is very difficult to say something more for the nature of this trend on the base only of these tendencies.

In our early study [4], we did a numerical time series analysis over the first version of Schove’s series from 1955 AD [5]. The time step in this series is the mean length of Schwabe–Wolf’s cycle ($Sc = 11.04$ years) during the continuous part of Schove’s series since 296 AD. The time series terms are the Schwabe–Wolf’s cycles magnitudes, which are pre-calculated on the base of magnitude scale by D. Schove. The used method is T – R periodogram analysis.

A central moment in this method is that the studied time series $F(t)$ is “scanned” by large number of simple periodic functions of type $f(t, T) = a_0 + A\cos(2\pi t/T) + B\sin(2\pi t/T)$ by using of least squares procedure. “ t ” is the corresponding number of time series term ($t = 0, 1, 2, N - 1$), that is, it is related to the time. “ a_0 ” is the mean value of $F(t)$ and $p = 3.14159$. Period T varies from some chosen minimal. Value T_0 (usually $T_0 = 2$ (time series step)) to other chosen maximal value T_{\max} by step “delta T ”. The last parameter could be not only equal or greater, but also essentially smaller than time series step. Specifically, for our aims, we used “delta T ” = 1, 0.5, 0.25, or 0.2 for most of our studies. For every fitting function $f(t, T)$, the coefficient of correlation “ $R(T)$ ” to original series $F(t)$ is calculated, as well as its statistical significance is estimated. The local and statistically significant peaks of $R(T)$ tabulated or graphical expressed function correspond to statistically significant cycles in the studied time series. In more details as well as in more aspects, the T – R method is described in [4].

It is clearly detected that the main cyclic component is a 204 year oscillation. By less statistical significance, there are also quasi-centennial multiplets in the range of 70–130 years, a 350 year cycle as well as a very long cyclic variation by duration of ~ 1100 –1200 years. The T – R spectra of radiocarbon series during the same period as the Schove’s series 3rd–20th centuries (based on INTAL93 radiocarbon time series, time step equal to 10 years) are very similar. The corresponding quasi-millennial oscillation is shorter – about 800 years.

Results and discussion

The results were obtained from time series analysis of one and the same data set – the recent part of Schove’s series (since 1000 AD), by using of two different methods – T – R periodogram analysis and method of Komitov and Kaftan [2] (see also [3] and reference therein). The method of Kaftan is a numerical technique called as the sequential analysis of dominated harmonics method. It is also based on the iterative least square method. The technique was used successfully for the Caspian Sea level change prediction and fully described in [6].

Results from both methods are very similar to each other (see Fig. 1). The bicentennial cycle is revealed as the most important for the long term solar activity kinematics during the last millennia.

The bicentennial solar cycle is well detectable by using of different time series methods in all quantitative historical or instrumental time series by duration 300–400 years or more.

The better understanding of the nature and behavior of the supercentennial nonlinear and upward after Maunder minimum trend is very important for a certain long term solar activity predictions for 21st century and beyond. How stable are the long term cycles and especially the bicentennial one? Is it a fundamental and permanent property of the solar dynamo?

The powerful quasi-bimillennial 2200–2400 year long, the so-called Hallstadzeit cycle, is the most powerful solar activity cyclic oscillation during the postglacial epoch – Holocene. It is very clear shown if the super decamillennial trend (by geomagnetic or mixed solar-geomagnetic origin) is removed from the long term tree rings radiocarbon series. It is good detectable even before Holocene – in Wurm Ice Epoch. The Hallstadzeit cycle could be obtained in radiocarbon series by using of different time series analysis methods.

First ideas concerning the structure of Hallstadzeit cycle are given by Damon and Sonett in 1991 [7]. Dergachev and Chistyakov suggest such more detailed one in 1993 (see [3] and the reference therein) and recently Komitov and Kaftan [2] on the base mainly of radiocarbon INTAL98 data and particularly, on the base of Schove’s series suggest even more detailed structure (Fig. 2). According to this model, every Hallstadzeit oscillation contains two waves by duration of 1100–1200 years, the first one is low, and the second one is higher. The first peak is a flat, plateau-like maximum, which is relatively continuous phase by duration of 500–600 years. The secondary minimum between the both quasi-millennial waves is not so deep like the starting and ending Maunder-type minimums. As it is shown, the present epoch (solar cycles from ~ 22 to 25) corresponds to the transition epoch between the initial active phase and “plateau” of the present Hallstadzeit cycle. It is an important fact, which indicates that other deep Maunder-type minimum is rather not possible to occur during 21st or next few centuries.

An essential feature of the bicentennial cycle is their amplitude modulation by Hallstadzeit. As it is shown in Fig. 3, the amplitude of 200 year cycle is highest during the Maunder-type minimums. It decreases during the upward and maximal phases and increases during the downward phases of Hallstadzeit. The last maximum, the present statement, and the expected next minimum in 21st century are shown in Fig. 3. The present epoch is characterized by decreasing of 200 year cycle amplitude. It follows by this one that the expected in this century 200 year solar minimum should be not so deep as to Spoerer one, but rather like to these of Dalton or Oort. Our model of Schove’s series for the last millenium, based on T – R periodogram analysis + their extrapolation for the 21st century, has been presented in [2,3]. We found that in Schove’s series, best expressed is the 200–210-year cycle, which next minimum should be expected near to calendar year 2061.

The role of other statistical important oscillations by durations in range of 50 to ~ 1000 –1200 years has also taken into account in the corresponding assembled model, based on T – R analysis [2]. It has been found as a result that supercentennial

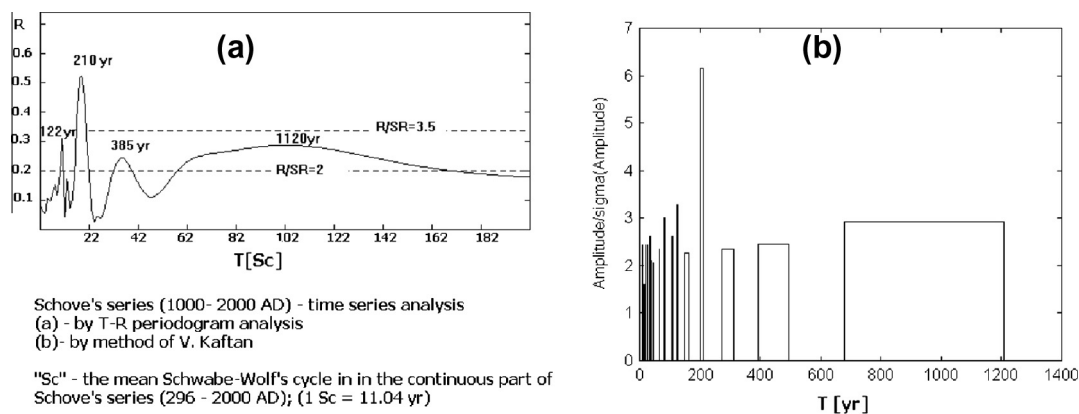


Fig. 1 The recent part of Schöve's series (1000–2000 AD) – time series analysis by two methods (left: by T - R periodogram method; right: by method of V. Kaftan).

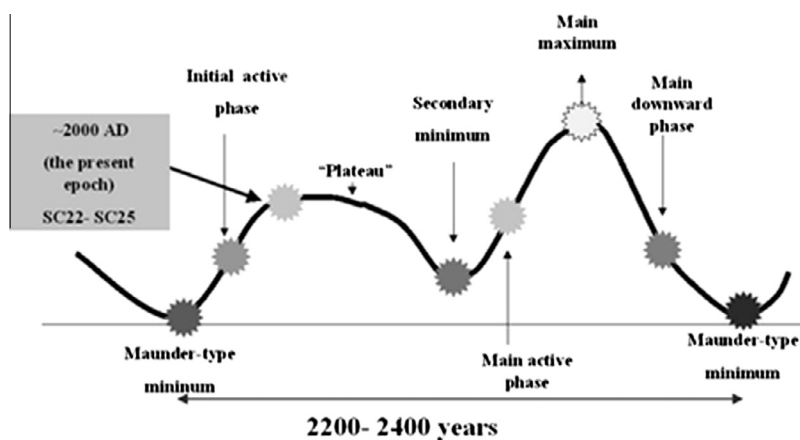


Fig. 2 The structure of 2200–2400 year (Hallstattzeit) cycle. All details by duration less than 300–400 years are smoothed.

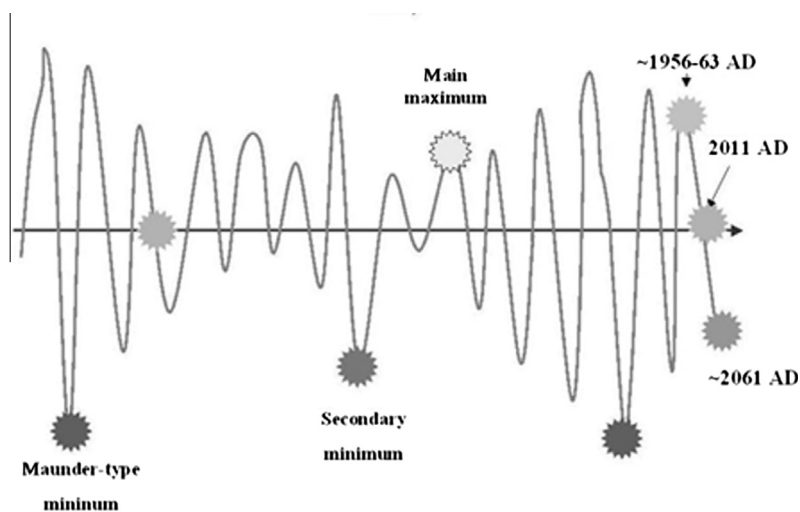


Fig. 3 The ~200 year cycle modulation by Hallstattzeit (scheme). The last 200 year cycle maximum near to sunspot cycle no. 19, the present epoch, as well as the next minimum near to 2061 AD are shown.

minimum with depth between these of Dalton and Oort should be occurred during the next decades. The deepest phase near to 2070–2071 AD should be reached. Obviously, it is caused by the main weight of bicentennial cycle. Almost the same predic-

tion has been made by using of Kaftan's method [2]. Predictions for coming supercentennial minimum could be made if other long historical or instrumental time series are also used (see [3] and the reference therein).

Let's consider the situation with the current sunspot solar cycle 24 and analyze its progress in the light long term solar activity dynamics. According Komitov's study from 2007 [8], a not strong criterion for coming soon long term solar minimum is the prolongation of sunspot cycles. The "smoothed start moment" of solar cycle 24 has been determined as November 6th 2008 \pm 42 days [9]. Thus, the previous solar cycle 23 length has been about 12.4 years, and it should be classified as a long one. The decreasing phase length is ~ 8.2 according to this result. Specifically, the very long downward phase of this cycle has been predicted successfully by Kaftan and Krainev in 2004–2005 [9]. We found that the smoothed 24th solar cycle magnitude points $Ri_{(max)} \approx 72 \pm 27$ in 2012 or 2013 [10]. It corresponds to beginning of a moderate supercentennial solar minimum. This prediction seems to be in very good agreement with the real progress of solar cycle 24 (see <http://www.swpc.noaa.gov/SolarCycle/>).

Conclusion

According to the presented, there predictions, which are based on historical or instrumental data sets with length in order of 300–400 years or longer a supercentennial Oort or Dalton-type solar minimum, should be started in the first half of 21st century. But its minimal phase will probably take place in the last half of the age. The validity of long term solar activity prediction scenario is strongly related to the problem of stability and amplitude modulation of solar cycles by quasi- and bicentennial duration by the longer ones – first of all Hallstadtzeit (2200–2400 year). This statement is strongly important for the present epoch. Solar cycle 24 should be expected to be rather moderate or even "moderate weak", as very strong or very weak.

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